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Reservoir Analysis and Fluid Effect Identification in Y-Field, Niger Delta Basin through Amplitude Versus Offset (AVO) Study

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Abstract

Amplitude versus offset (AVO) analysis has been a useful technique for reservoir study and has played a vital role in reservoir fluid characterisation. This approach makes use of the variation of amplitude of seismic data with offset or angle and this has been applied to the study of reservoirs in Y-field for the purpose of maximum production. Zoeppritz equation was used to produce synthetics for AVO modeling while two-terms Aki-Richard equations were used to generate various AVO volumes ranging from Intercept (A), gradient (B) and Scaled Poisson's Ratio Change (aA+bB) volumes. The results revealed good correlation between real seismic and Zoeppritz synthetics, an indication of good AVO modeling and a reliable AVO cubes. The reservoirs were classified as type II and Scaled Poisson's Ratio Change clearly identified units with hydrocarbon accumulation discriminating it from the effect of lithology. Therefore, the study concluded that AVO analysis can provide critical parameters in fluid identification and discrimination.

Keywords: Amplitude versus offset, fluid effect, reservoir, Zoeppritz equation, Aki-Richards equation and Scaled Poisson's Ratio Change.

1.0 Introduction

Zoeppritz, (1919) derived the amplitudes of the reflected and transmitted waves using the stress conservation and displacement across the layer boundary. Richards and Frasier, (1976) and Aki and Richards, (1980) refined the linearized approximation to Zoeppritz equations. The Aki-Richards equations are the most applicable and useful. Wiggins et. al., (1983) and Shuey, (1985) also worked on the Aki-Richards relation and algebraically rewritten it into a similar and simpler form. Fatti et al., (1994) derived another equivalent relation of Aki-Richard's equation and provided the third term of the equations which was used in the AVO volume generation. All these newer versions of the Zoeppritz, (1919) equation made the once ambiguous equation simple and easy to apply to solve critical reservoir problems and making AVO interpretation seamless. The AVO cross-

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plotting theory was developed by Castagna and Swan, (1997), Castagna et al., (1998) and Vern and Hilterman, (1995). Rutherford and Williams, (1989) produced a scheme of classification for AVO plotting of A and B response. It was later modified by Ross and Kinman, (1995) and Castagna and Swan, (1997). The scheme was used to identify various AVO classes as it relates to interpretation of AVO responses and used in this basinal study. Barh et al. (2021) predicted resistivity property from seismic volumes and logs. Suleymanov et al. (2022) predicted petrophysical rock properties from bulk density, P- wave and S-wave velocity logs. Abdulbariu and Raji (2023) used log analysis and rock physics study for reservoir definition and delineation in Y-Field with the reservoir hosting hydrocarbon clearly revealed. Didenko (2023) also predicted few reservoir properties from pseudo wells and the pseudo-logs represented the missing data in the well.

2. Geological background and Methodology

The research area is part of Niger Delta basin which is one of the most prominent basin in Nigeria. It is characterised with lithological and structural complexities. The study area main geology include; Akata Formation, Agbada Formation and Benin Formation which are found in the delta. Akata is the oldest, followed by Agbada and finally Benin Formation which is the youngest. Akata shale and some intercalated shaly units of Agbada Formation served as the source rocks, while Agbada Sandstone unit and some turbidites in the deep sea served as the reservoir rock units which host the hydrocarbon. All these have been described and documented in the work of the following authors such as Bouvier et al., (1989), Doust and Omatsola, (1990), Evamy et al., (1978), Etu-Efeotor, (1997), Tuttle et al., (1999) and Reyment, (1965).

2.1 Methodology

Logs of various types such as gamma, resistivity, density, p-wave, s-wave, water saturation, volume of clay etc were used in this study for lithological and fluid identification and discrimination. The log suites were supplied by Addax Petroleum Nigeria Limited (APNL). The logs were analysed and interpreted. The density (ρ), p-wave (Vp) and s-wave (Vs) were used to generate the Zoeppritz synthetics using Zoeppritz equation at each well position, The synthetics were compared with real seismic in AVO modeling. The P-wave was used to provide the interval velocity and was used alongside with Aki-Richards two-term equation to produce various AVO volumes especially Scale Poisson's Ratio Change (aA+bB) cube.

2.2 Zoeppritz Equations

The Zoeppritz equations are cumbersome but the simplified forms are obtained at normal incidence ($\theta = 0^0$) that is, where there is no mode conversion, the equations give simple values for reflection and transmission coefficients as follows:

$$R_S(0^0) = R_{S0} = 0, \quad (1)$$

$$T_S(0^0) = T_{S0} = 0, \quad (2)$$

$$R_P(0^0) = R_{P0} = \frac{\rho_2 V_{p2} - \rho_1 V_{p1}}{\rho_2 V_{p2} + \rho_1 V_{p1}}, \quad (3)$$

$$T_P(0^0) = T_{P0} = \frac{2\rho_1 V_{p1}}{\rho_2 V_{p2} + \rho_1 V_{p1}} = 1 - R_{P0} \quad (4)$$

These equations reveal that there is no S-wave component at incidence angle of zero degree and that both the reflection and transmission coefficient are related and dependent on changes in the acoustic impedance (ρV) across the layer boundary.

2.3 The Two-Term Aki-Richards Formula

Two-term Aki-Richards formula was used to obtain Intercept and Gradient from seismic data. It was obtained from the Wiggins form of Aki-Richards equation as satated below:

$$R_P(\Theta) = A + Bsin^2(\Theta) + Ctan^2(\Theta)sin^2(\Theta) \tag{5}$$

By removing the C term, the equation reduces to:

$$R_P(\Theta) = A + Bsin^2(\Theta) \tag{6}$$

A and B are defined as

$$A = \frac{1}{2}\left[\frac{\Delta V_P}{V_P} + \frac{\Delta\rho}{2\rho}\right], \qquad B = \frac{1}{2}\frac{\Delta V_P}{V_P} - 4\left[\frac{V_S}{V_P}\right]^2 \frac{\Delta V_S}{V_S} - 2\left[\frac{V_S}{V_P}\right]^2 \frac{\Delta\rho}{\rho},$$

3. Results and Discussion

The well log study revealed that the reservoirs in well Nd-8gi (Figure 1) does not show the presence of hydrocarbon as revealed by their resistivity and their density values which were used in the fluid discrimination procedure as there were no anti-tracking between the two logs. But several oil and gas bearing units were found within the well Oks-2 (Figure 2) with characteristics anti-tracking between the resistivity and density. They occurred at different depth interval within the field. It can be seen that in Figure 2 at Hor 7, Hor 8, Hor 9, Hor 10, Hor 11, Hor 13, Hor 15, Hor 18 and Hor 19 reservoirs, as the resistivity increased, the density dropped to minima because, hydrocarbon has high resistivity low density compared to brine and hence those reservoirs were hydrocarbon saturated. They also showed very low water saturation (Sw) and hence high hydrocarbon saturation (Shc).

The AVO modeling for the two wells gave a very good match, making the AVO results reliable and dependable and the results were presented as Figures 3 and 4. Again, as can be observed from the result of the modeling, the major events in the Zoeppritz synthetic corresponded with event on the real seismic Figures 3 and 4). From the logs of Figure 1, there was no hydrocarbon. For well Oks-2 (Figure 4) those major events mostly occurred in the oil bearing intervals. Because of wave attenuation at depth where the amplitude of the seismic data begin to diminish, the events on the real seismic became faded but remained conspicuous on the Zoeppritz synthetic (since it is a model) especially at the Oks-2 location within the angle range of 0-15^0. The prestack 3-D seismic volume was presented in Figure 5 and it showed several high amplitude regions. The product of intercept A and gradient B does not really showed conspicuous result because, the reservoirs are not class III AVO type but class II and therefore, the Scaled Poisson's Ratio Change volume which is good for this class was generated and presented as Figure 6. It can be observed that the AVO cube was characterised with several high anomalous AVO responses different from the background response. These are reservoirs that contain hydrocarbon and they occurred at Hor 3, between Hor 3 and 7, at Hor 8, Hor 11, Hor 13, Hor 15 and at other locations away from the already drilled sites as revealed by the AVO cube.

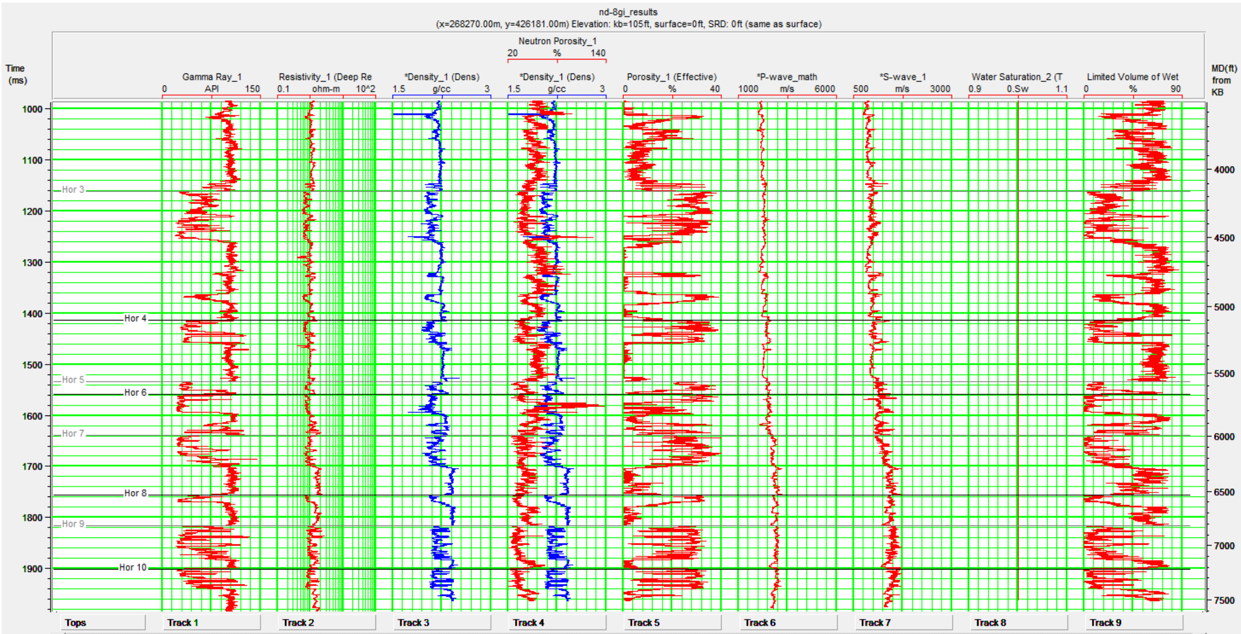

Figure 1: Well Nd-8gi showing some selected logs with well tops. Track 1: Gamma log, Track 2: Deep resistivity, Track 3: Density, Track 4: Density (blue) and Neutron log (red), Track 5: Effective porosity, Track 6: P-wave, Track 7: S-wave, Track 8: Water saturation, and Track 9: Volume of shale/clay.

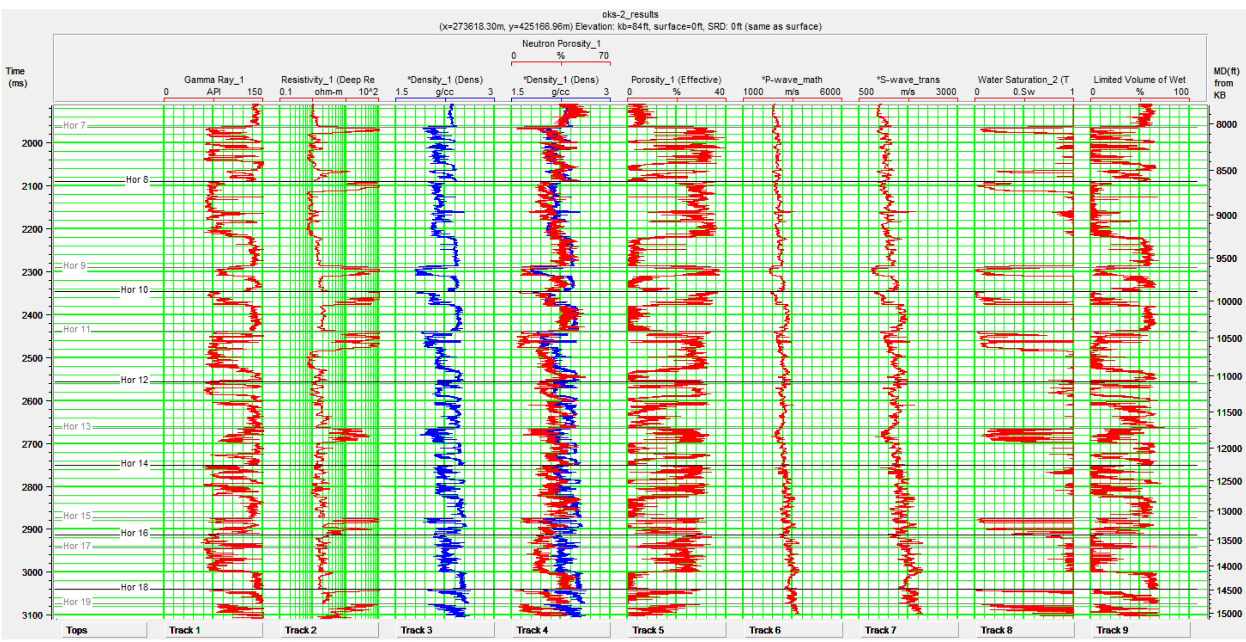

Figure 2: Well Oks-2 showing some selected logs with well tops. Track 1: Gamma log, Track 2: Deep resistivity. Density, Track 4: Density (blue) and Neutron log (red), Track 5: Effective porosity, Track 6: P-wave, Track 7: S-wave, Track 8: Water saturation, and Track 9: Volume of shale/clay.

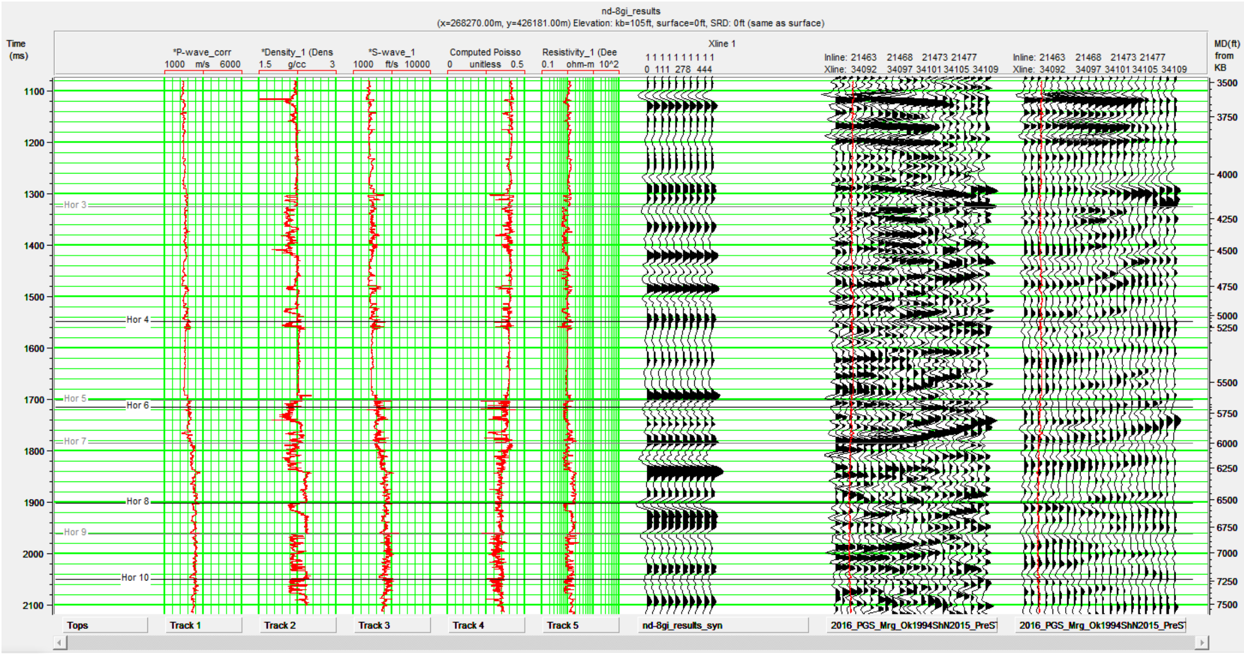

Figure 3: Nd-8gi log correlation of Zoeppritz synthetic with real seismic (0-15^0 and 10-30^0) angle range prestack seismic data (see the good correlation between the two, an indication for good modeling for AVO analysis)

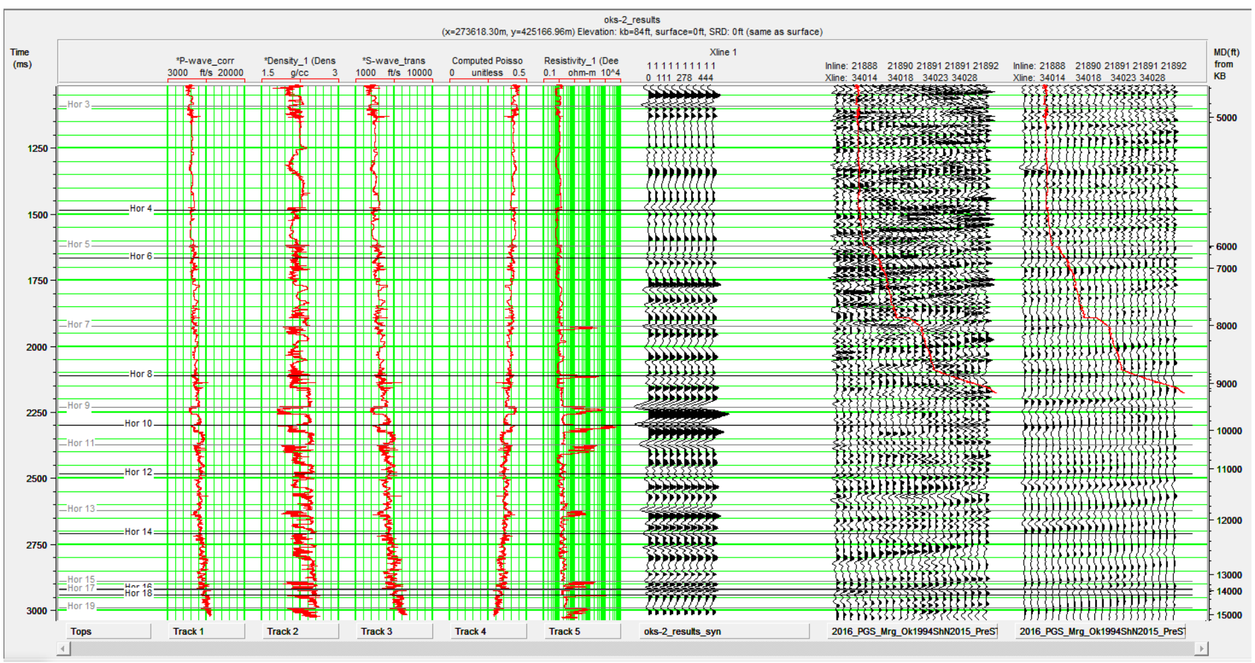

Figure 4: Oks-2 log correlation of Zoeppritz synthetic with real seismic (0-15^0 and 10-30^0) angle range pre-stack seismic data

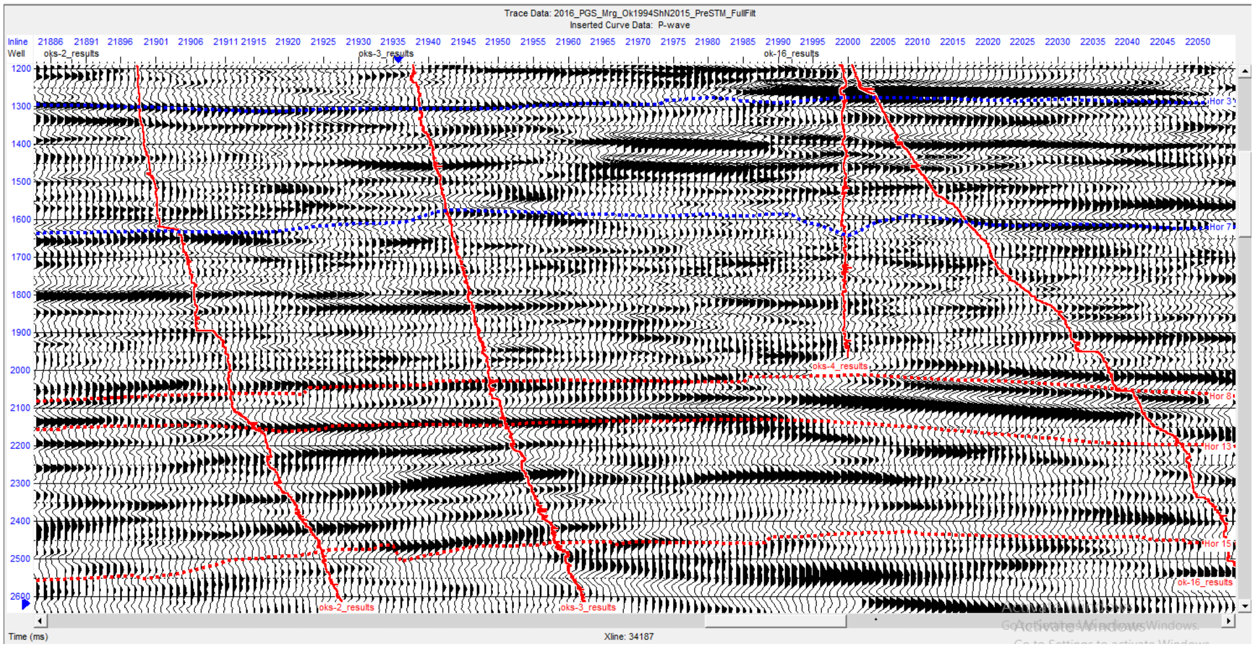

Figure 5: The prestack 3-D seismic volume with wells Oks-2, Oks-3, Oks-4 and Ok-16 inserted

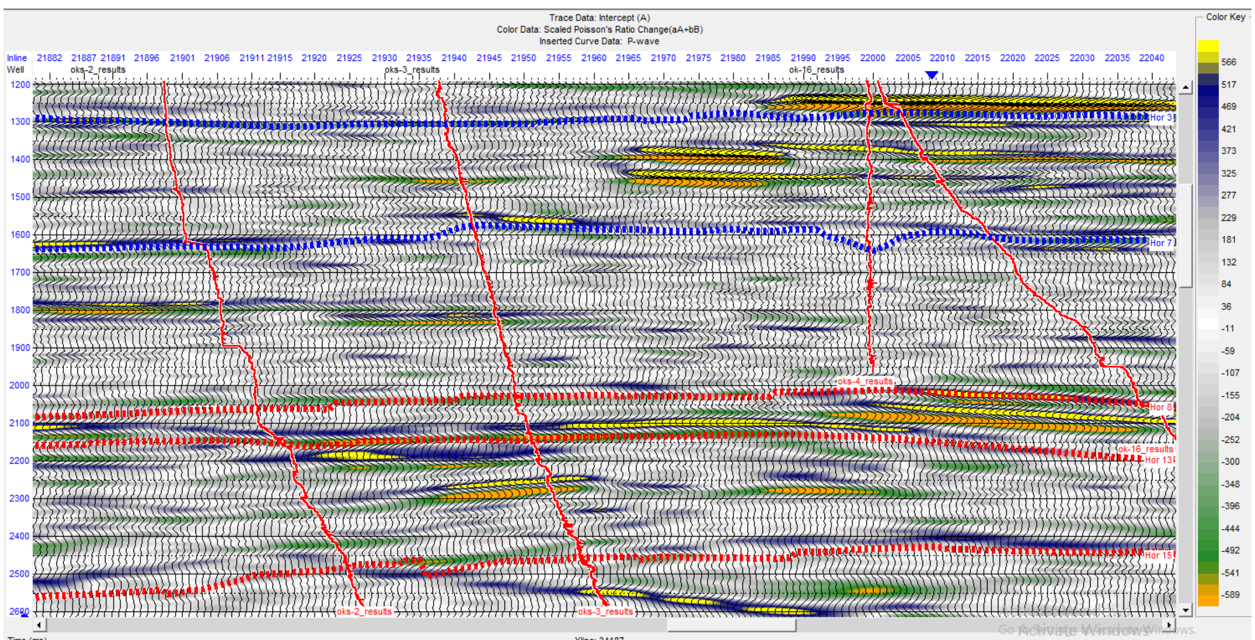

Figure 6: The scaled Poisson's ratio change volume (aA + bB) showing clearly the AVO anomaly response for class II isolating various sandy units containing hydrocarbon, yellow and orange indicate high and low AVO responses respectively

It can be observed that some wells were not well deviated to maximally exploit the nearby reservoirs. The AVO result had characterised the reservoirs into regions containing hydrocarbon underlain by brine as seen as yellow and orange colour respectively.

Figures 7 and 8 are results of both Hor 8 and Hor 11 respectively obtained from the Scaled Poisson's Ratio Change volume. Reservoir Hor 8 (Figure 7) had more promising hydrocarbon zones. Amplitude envelope over the reservoir indicated regions of probable hydrocarbon occurrences. They were also characterised by high AVO responses and they occurred at some few locations in the northwest, northeast, southwest and central portion of the map.

But reservoir Hor 11, the Amplitude Envelope of the Scaled Poisson's Ratio Change showed very few locations of hydrocarbon presence. Identified by high AVO response which occurred and almost scattered at some portions within the reservoir as shown in Figure 8.

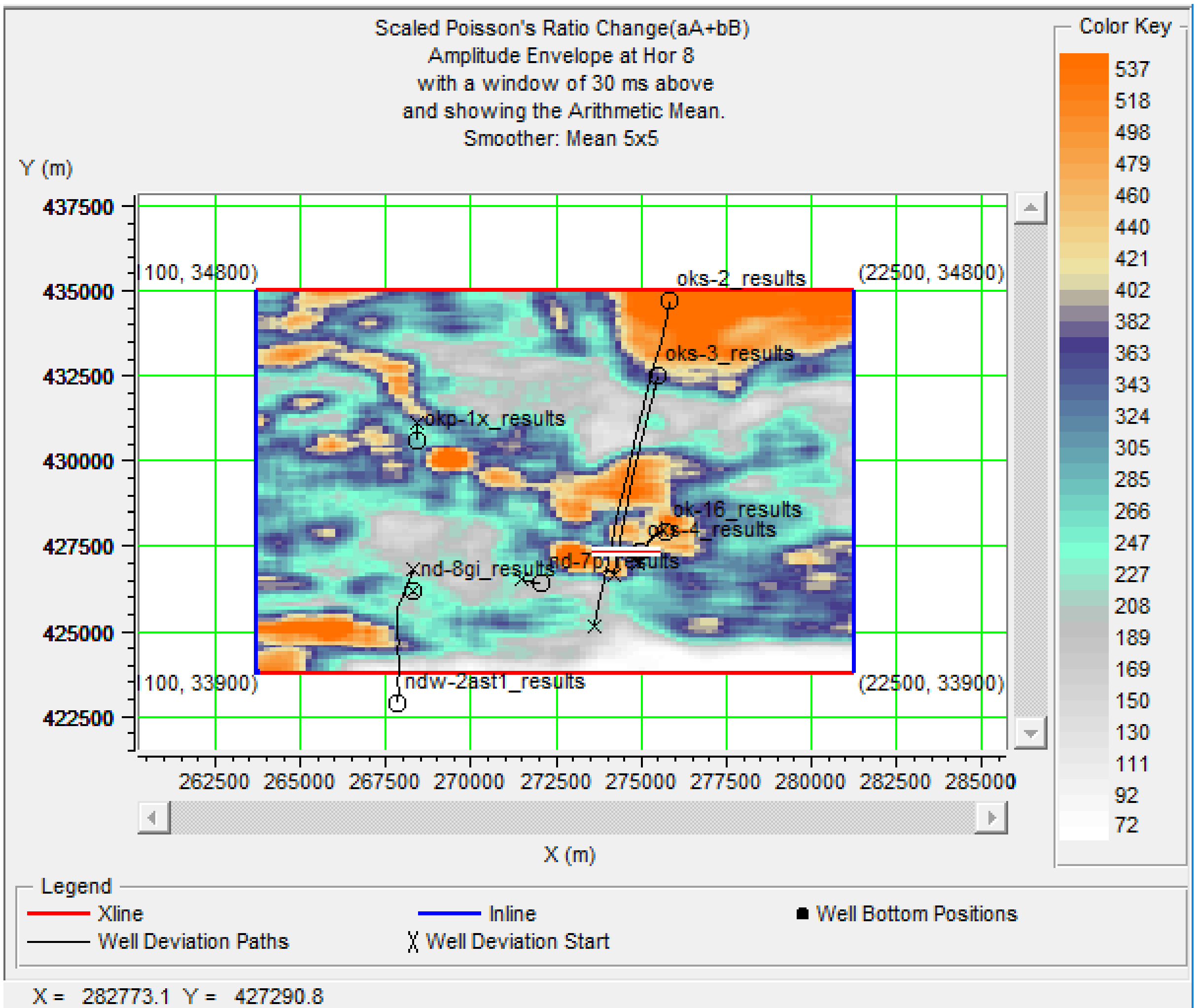

Figure 7: Amplitude envelope of the AVO "Scaled Poisson's ratio" across Hor 8 reservoir showing region of likely hydrocarbon accumulation (orange colour) which are indication for High AVO responses for either lithology or fluid or both

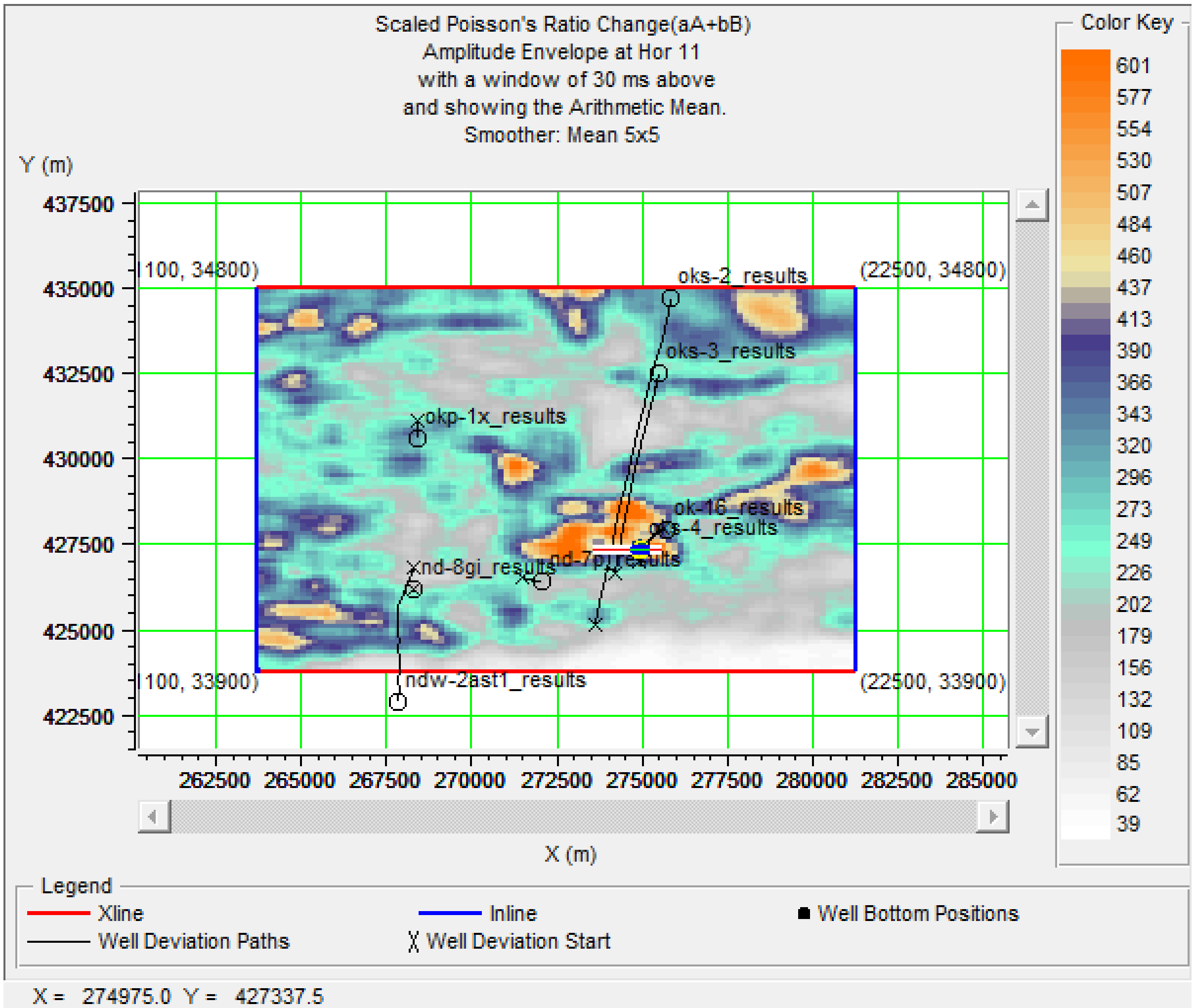

Figure 8: Amplitude envelope of the AVO "Scaled Poisson's ratio" across Hor 11 reservoir showing region of likely hydrocarbon accumulation (orange colour) which are indication for High AVO responses for either lithology or fluid or both

4. Conclusion

Integrated log analysis, AVO modeling and AVO volumes have been used to characterise the reservoir in the Y-field. The log analysis identified several hydrocarbon- and water-bearing intervals in both two wells presented. The reservoir saturated with oil showed anti-tracking between resistivity and density log (because of high resistivity and low density properties of hydrocarbon) while the brine saturated units does not show any anti-tracking instead the two logs tracked one another. The AVO modeling revealed excellent correlation between real seismic and Zoeppritz synthetics which finally gave rise to good AVO cubes of Scaled Poisson's ratio change. The volume clearly depicted hydrocarbon intervals and distinguished it from the background AVO response. Several such intervals were identified even away from existing drilled wells and pinpointed new prospect areas for future drilling. Fluid effect and the effect due to brine and lithology were shown by the AVO volume and hence reservoir characterisation. Some wells were not properly placed while some were not deviated well to capture and tap from the nearby oil saturated reservoirs at shallower or even deeper depth. It can concluded that, log analysis, AVO modeling and Scaled Poisson's ratio change

(AVO) volume can serve as a mean of providing needed important reservoir parameters for characterising reservoir which ultimately led to fluid identification and discrimination.

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